The Stereo-Electroencephalography Methodology

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KEYWORDS

• Epilepsy surgery • Stereo-electroencephalography • Stereotaxy • Morbidity • Seizure outcome

KEY POINTS

- Stereo-electroencephalography (SEEG) defines the anatomic boundaries of the cortical and subcortical brain areas responsible for primary generations and early propagation of the epileptiform activity.
- Both frame-based and frameless techniques can be used for implantation of SEEG electrodes.
- Vascular imaging is fundamental for the safe implantation of SEEG electrodes. Attention to the vascular anatomy is essential to reduce the risk of hemorrhagic complications.

INTRODUCTION

One of the main goals of epilepsy surgery is the complete resection (or complete disconnection) of the cortical areas responsible for the primary organization of the epileptogenic activity. This area is also known as the epileptogenic zone (EZ). Because the EZ can eventually overlap with functional cortical areas (eloquent cortex), preservation of these necessary brain functions is another goal of any surgical resection in patients with medically refractory epilepsy.[1–7]

Because successful resective epilepsy surgery relies on accurate preoperative localization of the EZ, a preoperative evaluation is necessary to obtain the widest and most accurate spectrum of information from clinical, anatomic, and neurophysiologic aspects, with the ultimate goal of performing an individualized resection for each patient. The noninvasive methods of seizure localization and lateralization (scalp electroencephalography [EEG], imaging, magnetoencephalographic [MEG], etc) are complementary and results are interpreted in conjunction, in the attempt to compose a localization hypothesis of the anatomic location of the EZ. When the noninvasive data are insufficient to define the EZ, extraoperative invasive monitoring may be indicated. Stereo-electroencephalography (SEEG) is among the extraoperative invasive methods that can be applied in patients with medically refractory focal epilepsy to define anatomically the EZ and the possibly related functional cortical areas. Clinical aspects of the SEEG method and technique are discussed in this article.

HISTORY AND BASIC PRINCIPLES RELATED TO THE STEREO-ELECTROENCEPHALOGRAPHY METHODOLOGY

The SEEG method was originally developed by Jean Talairach and Jean Bancaud during the 1950s[8] and has been mostly used in France, and later in Italy, as the method of choice for invasive mapping in refractory focal epilepsy.[7,9–31] In France, after the development of the stereotactic techniques and frames, which were applied initially for abnormal movement disorder surgery, Jean Talairach devoted most of his activity to the field of epilepsy. Bancaud joined

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Talairach in 1952. The new methodology created by both physicians led them to depart very quickly from another approach that was limited to the superficial cortex. Wilder Penfield and colleagues at the Montreal Neurologic Institute did likewise. Talairach's innovative thinking was to implement a working methodology for a comprehensive analysis of morphologic and functional cerebral space. His atlas on the telencephalon, published in 1967, perfectly illustrates the new anatomic concepts for stereotaxis.[32] The development of tools, adapted to a new stereotactic frame designed by Talairach and colleagues,[32] allowed the Saint Anne investigators (Talairach and Bancaud) to propose the functional exploration of the brain by depth electrodes, allowing the exploration of both superficial and deep cortical areas. The debut of SEEG was in 1957, when the first implantation of intracerebral electrodes for epilepsy was performed on May 3 in Saint Anne Hospital (Paris, France). By departing from the then current methods of invasive monitoring, such implantations allowed for the exploration of the activity of different brain structures and for the recording of the patients' spontaneous seizures. This development was something that Penfield's method of investigation failed to achieve. In 1962, Talairach's and Bancaud's new technique and method was called "the Stereo-Electro-Encephalography."[11]

The principles of SEEG methodology remain similar to the principles originally described by Bancaud and Talairach, which are based on anatomoelectroclinical correlations (AEC) with the main aim to conceptualize the 3-dimensional (3D) spatial–temporal organization of the epileptic discharge within the brain.[7,11–13,22–31,33,34] The implantation strategy is individualized, with electrode placement based on preimplantation hypotheses that takes into consideration patient's seizures' electroclinical correlations and their relation with a suspected lesion. For these reasons, the preimplantation AEC hypotheses formulation is the single most important element in the process of planning the placement of SEEG electrodes. If the preimplantation hypotheses are incorrect, the placement of the depth electrodes will be inadequate and the interpretation of the SEEG recordings will not give access to the definition of the EZ.

CHOOSING STEREO-ELECTROENCEPHALOGRAPHY AS THE APPROPRIATE METHOD FOR EXTRAOPERATIVE INVASIVE MONITORING

After the establishment of the diagnosis of pharmacoresistant epilepsy (defined as a failure to respond to ≥2 adequately chosen and used antiepileptic medications),[35] a preoperative evaluation is indicated with 2 main goals: (1) mapping of the AEC network leading to the identification of the EZ and its extent, and (2) assessment of the functional status of the epileptogenic region(s). Achievement of both goals will lead to optimization of postresection seizure and functional outcomes. As briefly discussed, multiple techniques may be used to achieve the stated goals. Scalp video EEG monitoring is needed to confirm the diagnosis of focal epilepsy (including interictal and ictal EEG recordings) and to identify the cortical structure of the hypothetical networks that may be involved in seizure organization (through analysis of the recorded clinical and electrical semiology). Data obtained via scalp video EEG monitoring may lead to the formulation of clear AEC hypotheses. Further validation of the anatomic hypothesis is achieved through structural imaging (the identification of lesion on MRI), with or without metabolic imaging (including fluorodeoxyglucose–PET hypometabolism that may point to focal regions of cortical dysfunction). Other studies may include ictal single photon emission computed tomography, MEG, and EEG-functional MRI.[6,36,37]

These noninvasive studies identify the EZ in more than one-half of patients undergoing preoperative workup (around 70% of the patients who are operated on at Cleveland Clinic in 2012; unpublished data) Unfortunately, a formulation of a clear and unique AEC hypothesis may not be possible in the remaining 30% of patients. In such a case, focal or focal/regional epilepsy is likely, but the noninvasive phase I cannot enable caregivers to decide between 2 or 3 hypotheses in the same hemisphere. Alternatively, there is a sound regional hypothesis but not enough argument in favor of 1 hemisphere or hypotheses are generated but the exact location of the EZ, its extent, and/or its overlap with functional (eloquent) cortex remain unclear. Consequently, these patients may be candidates for an invasive evaluation using intraoperative electrocorticography or extraoperative methods such as subdural grids/strips, subdural grids combined with depth electrodes, and SEEG.[38]

In summary, the primary indications for an invasive evaluation in focal pharmacoresistant epilepsy (with the main purpose of direct cortical recording) are to address the main challenges and limitations of various noninvasive techniques. Based on the limitations outlined of the various noninvasive techniques, an invasive evaluation should be considered in any 1 of the following cases.